APPENDIX C (continued)

SITE AND SAMPLE DESCRIPTIONS

The purpose of these descriptions is to document the nature of the bedrock, the presence of field-scale structures such as faults, fractures, breccia zones, and other features that affect rock permeability, and the existence of secondary mineral deposits indicating that water has moved through the rocks. The descriptive process is in progress and many of the descriptions remain to be done or are incomplete, lacking either site or sample information. The descriptions given here include systematic sampling sites and sites that were chosen for the existence of a possible flow path, water-laid mineral deposit, or representative bedrock.

As described above, particular attention has been devoted to features with implications for continuity of flow paths. In the context of Yucca Mountain geology, the term “syngenetic” refers to features that formed during the deposition or cooling of a pyroclastic unit. Syngenetic features such as cooling joints and some fracture zones could serve as fluid conduits, but do not normally extend beyond the boundaries of the host unit. For example, a cooling joint in the Topopah Spring Tuff with geochemical evidence of recent flow must have received its fluid input from a different conductive feature in the overlying nonwelded tuff. In contrast, a fault with evidence of repeated movement could by itself be a direct flow path from the surface to the Topopah Spring Tuff.

(Sta. 1+98)

The bedrock is densely welded, devitrified lithophysal Tiva Canyon Tuff from the eastern wall of the Bow Ridge fault zone. The Bow Ridge fault is a westward-dipping normal fault with displacement downward to the west. The rock is fractured and fragmental. Individual fragments are more than 2 cm across, very irregular due to the lithophysae, and mostly angular to subangular.

The rock contains about 10% lithophysal cavities up to 3 cm across. The cavities have bleached borders up to 1 cm thick. Vapor-phase minerals in the cavities are feldspar, crystalline silica, and Fe-Ti oxides, all less than 1 mm. There may be some clay as well. Less than 5% of the cavities contain sprays of weakly UV-fluorescent drusy quartz overlying the vapor-phase minerals. Rock surfaces have less than 1% coverage of dendritic to diffuse spots of manganese minerals and a more widespread overcoating of powdery white material. The existence of these coatings suggests that the bedrock is highly fractured even beyond the boundary of the fault zone.

E007 (Sta. 2+3)

This bedrock sample is medium-grained nonwelded pre-Rainier Mesa tuff from the downthrown western wall of the Bow Ridge fault. There is no evidence of fracturing or fracture-filling minerals. The original glassy components of the rock have been completely replaced by zeolites, probably clinoptilolite. The pyroclastic constituents included about 30 to 50% of mostly white pumice clasts less than 1 cm across, 10 to 20% dark lithic grains less than 3 mm across, less than 5% phenocrysts of mostly feldspar and lesser bleached biotite, and the remainder of fine ash. No calcite or UV-fluorescent silica is present.

E008 (Sta. 1+99.8)

This sample was collected from within the Bow Ridge fault zone which is several meters wide at the ESF tunnel level. The fault gouge is composed of fragments of densely welded, devitrified Tiva Canyon Tuff. Individual breccia clasts range from more than 5 cm across to less than 150 µm. There are local segregations of the fine-grained material. Larger clasts are somewhat rounded.

Some of the larger clasts have dendritic coatings of manganese minerals. All clasts are coated with a less than 1 mm thick powdery white layer composed of feldspar, smectite, quartz, tridymite, cristobalite, calcite, and hematite, in order of decreasing abundance (see Table III). Most of this may be material of vapor-phase and lower-temperature hydrothermal origin redistributed onto the surfaces of the breccia clasts. There is local tight cementation of the fine-grained breccia and adjacent coarser clasts by less than 1 mm thick coatings of less than 0.2 mm calcite crystals whose overall abundance is undetermined. The calcite is also covered with white powder. No UV-fluorescent or otherwise visually identifiable silica is present.

APPENDIX C (continued)

SITE AND SAMPLE DESCRIPTIONS

E010 (Sta. 1+99.8)

This sample from the Bow Ridge fault zone consists of ~2- to 5-cm rubble. The rubble clasts are subangular to subrounded and are either intact densely welded, devitrified Tiva Canyon bedrock or loosely cemented Tiva Canyon breccia, in about equal proportions. The brecciated tuff consists of 1-cm fragments of fractured tuff cemented by gray-white, slightly clayey, <<1-mm material. Rubble clasts of intact rock commonly have 1 mm-thick coatings of powdery gray-white material.

Most rock fragments have scattered surficial patches of dendritic manganese minerals. On newly broken breccia clast fracture surfaces, a few of the manganese patches surround highly weathered mafic minerals. No calcite or UV-fluorescent silica was observed.

E011 (Sta. 1+99.8)

This sample consists of mostly coarse (>1 cm) rubble and minor fine-grained breccia from the Bow Ridge fault zone. The rubble clasts are all densely welded, devitrified Tiva Canyon Tuff and are mostly subequant and subangular.

About 95% of the brecciated rock surfaces are coated with a <1 mm-thick layer of pale pink to buff powdery material. In a few places where the coating is thin or absent, discontinuous coatings of dendritic manganese minerals cover less than 5% of the rock surfaces. In the fine-grained breccia and on a few coarse clast surfaces, there are <<1 mm-thick coatings of <0.5 mm calcite crystals with probably rhombohedral morphology. Most of the calcite shows little fluorescence, except for a few 1 to 2 mm wide patches that fluoresce white (more strongly in long- than in short-wave UV light). Some calcite may have a very thin, visually undetectable, coating of opal because it shows weak yellow-green fluorescence in short-wave UV light. The calcite does not form a dense cement, and there are small cavities <1 mm within the fine-grained breccia that lack calcite or powdery coatings.

E020 (Sta. 24+68)

The sample site is a partly syngenetic rubbly breccia in sparsely lithophysal densely welded, devitrified Topopah Spring Tuff. Individual breccia clasts, up to at least 10 cm across, are coated on most surfaces with vapor-phase feldspar and silica. Feldspar is more common in the lithophysae and silica is more common on the fracture surfaces. The lithophysae are up to 2 cm across, with bleached borders.

The clasts have less than 1% coverage of surface-conformal crusts less than 1 mm thick of semi-aligned quartz crystals. There are also isolated patches of <1 mm drusy quartz crystals and associated rare botryoids of silica with granular surfaces (probable opal-CT). None of this silica is UV-fluorescent. All of this silica is partly overgrown by calcite. The calcite, in <1 mm equant crystals or <1 cm blades, fills some lithophysae (blades) and covers broken rock surfaces with or without underlying vapor-phase coatings (equant and blades). UV-fluorescent opal, in not quite clear <1 mm botryoids, are locally associated with calcite and have an overall abundance of 1 to 2%. The opal exists as overgrowths and intergrowths or inclusions in calcite. There are also <1 mm spheres of powdery white, possibly fluorescent silica preserved only as inclusions in calcite.

E027-1 (Sta. 11+00)

This systematic sample consists of moderately to densely welded, devitrified Topopah Spring Tuff. The rock is red-brown, with ~10% phenocrysts of feldspar, biotite, Fe-Ti oxides, other mafic minerals, and quartz. Pumice lapilli ≤2 cm across comprise ~25% and are vapor-phase altered to feldspar, crystalline silica, biotite, and other mafic phases. There are no obvious fractures in the sample, but local irregular, discontinuous breaks exist and are identifiable by uncommon Mn mineral coatings in ≤1 mm patches.

Rusty oxidation of mafic minerals is common, but not all grains are affected. Within the vapor-phase altered pumice lapilli are common but not ubiquitous <1 mm deposits of white translucent clay. Many of the deposits have forms that are reduced shape of the cavities in which they occur. Clay deposits are present in cavities newly exposed by breaking the sample. These relations suggest that the clays are of *in situ* origin. No short-wave UV-fluorescent phases were observed.

APPENDIX C (continued)

SITE AND SAMPLE DESCRIPTIONS

E028 (Sta. 12+44)

The host bedrock is densely welded, devitrified, nonlithophysal, crystal -rich Topopah Spring Tuff. The sampled structure is a set of two near-vertical cooling cracks 30 cm to 1 m apart, with the intervening rock cut by a second set of sub-horizontal cooling cracks perpendicular to the main fractures. This feature is traceable from invert to crown on both ribs of the tunnel. Similar features are spaced laterally about 10 to 20 m apart.

The sampled rock contains about 10-15% phenocrysts of mostly alkali feldspar. Pumice lapilli constitute about 10% and commonly contain vapor-phase alteration cavities up to 2 cm across. The main secondary mineral in the vapor-phase cavities is clear to white crystalline silica. The prominent cooling cracks have widespread but incomplete coatings, less than 1 mm thick, of mostly white, granular to arborescent, non-UV-fluorescent silica, probably a vapor-phase product. Some cooling cracks and other, more irregular cracks, have 1 to 2 mm thick veneers of less than 1 mm tuff detritus cemented in place by UV-fluorescent botryoidal silica, mostly blue-gray and slightly translucent. Locally, the botryoidal texture grades into surface-conformal aggregates of subparallel 1 to 2 mm drusy quartz crystals. This cement locally overlies the vapor-phase silica. Isolated aggregates of drusy quartz are perched along fractures, especially fracture intersections. The dominant botryoidal silica cement also contains some white and nearly opaque silica. A small amount of clear sub-botryoidal opal overlies the rest of the silica cement, especially in depressions. No calcite was observed.

E029-1 (Sta. 13+00)

The sample is densely welded, devitrified Topopah Spring Tuff with moderately to densely welded, mm- to cm-scale pumice lapilli. Vapor-phase alteration is ubiquitous in the pumice lapilli. Lithophysal cavities contain mm-scale vapor-phase crystals of feldspar, hematite, and rare fibrous amphibole. No UV-fluorescent minerals were observed.

E030 (Sta. 13+67)

The sampled material is rubble composed of subangular to subrounded clasts of densely welded, devitrified crystal-rich Topopah Spring Tuff. The rock is slightly crumbly due to pervasive vapor-phase alteration of the pumice lapilli to feldspar, crystalline silica, and Fe-Ti oxides. The surfaces of some of the larger rubble clasts exhibit domains of <1 mm rock fragments cemented by vapor-phase minerals, and some areas of the rubble surfaces have coatings of vapor-phase minerals extending beyond the boundaries of altered pumices. These textural relations suggest that brecciation was at least partly syngenetic. No calcite or UV-fluorescent silica was observed.

E031 (Sta. 14+00)

This sample is composed of moderately to densely welded, devitrified Topopah Spring Tuff. Flattened, elongate pumice lapilli are up to 5 cm long and have been highly modified by vapor-phase crystallization. The pumices now have a cellular “bubble” texture, with individual cells from <1 mm to ~1 cm across. The mineralogy of the <1-mm vapor-phase crystals is mostly alkali feldspar and silica (forming the walls of the cells), with lesser amounts of biotite, Fe-Ti oxides, amphibole, and hematite. No UV-fluorescent mineral phases were observed. The sample is unfractured, although the flattened pumices may provide partings in the rock.

E033-1 (Sta. 14+41)

The sample consists of fragments, from <0.1 mm up to 3 cm across, of mostly densely welded, devitrified, crystal-rich Topopah Spring Tuff. Phenocrysts, ~15% of the rock, are feldspar, Fe-Ti oxides, and rare biotite. Local pumice-like areas are moderately welded and devitrified, but with well preserved glassy filament forms. Whitish pumices contain abundant vapor-phase minerals, mostly tridymite, feldspar, hematite, and amphibole.

APPENDIX C (continued)

SITE AND SAMPLE DESCRIPTIONS

There are a few mm- to cm-scale, ~1 to 2 mm thick crusts of ~1 mm drusy quartz crystals that do not fluoresce in UV light. The quartz is locally overgrown by ~1 mm flat prismatic calcite crystals. The base of one quartz crusts contains relict botryoidal silica that fluoresces green in short-wave UV light. There are cm-scale domains of ~1 mm rock fragments cemented by subpoikilitic equant to flat prismatic calcite crystals that fluoresce blue-white weakly in short-wave UV light.

Round, not botryoidal, flat blobs of blue-gray translucent silica <1 mm across occur as isolated deposits on calcite and less commonly on quartz. In several places, the calcite crystals have grown after silica deposition, partly to completely engulfing the silica deposits. These growth additions are commonly bounded by crystal faces surrounding the silica deposits. Less common deposits on calcite are <1 mm aggregates of transparent, slightly yellow silica. Both types of silica fluoresce green in short-wave UV light.

E035 (Sta. 15+05)

The sampled rock is a calcite-cemented, mostly syngenetic breccia of densely welded, devitrified Topopah Spring Tuff. The maximum clast size is about 2 cm. Most fragments are coated with <1 mm vapor phase minerals, mostly feldspar, silica, and minor Fe-Ti oxides. Slightly disaggregated vapor-phase minerals also serve as breccia matrix. A few clasts may have smectite-zeolite-silica alteration. A newly separated fracture surface shows the clay-rich clasts and pink-gray clay fracture coatings.

The breccia is tightly cemented by poikilitic calcite that comprises about 30% of the rock. In rare cavities within the cement, <1 mm across, the calcite has flat rhombohedral terminations. A prominent irregular fracture surface has a 0 to 2 mm-thick coating of flat rhombohedral calcite crystals <2 mm across. Overlying this calcite are <1 mm spots of silica that are mostly whitish, waxy, and subopaque, rarely clear. The silica, with an overall abundance on the fracture surface of <2%, fluoresces green in short-wave UV light. There are very rare manganese mineral coatings, mostly on tuff fragments, but also possibly on adjacent calcite crystals.

E036, E036-1 (Sta. 16+12)

This sample consists of broken rock and a separated cooling joint in densely welded, devitrified crystal-rich Topopah Spring Tuff, with calcite infilling. One rock fragment has a smooth surface coated with loosely adhering powdery vapor-phase material. Vapor-phase cavities in pumice lapilli are coated with feldspar, silica, and Fe-Ti oxides. Most cavities have infillings of calcite over the vapor-phase minerals.

The separated cooling joint was initially filled with botryoidal chalcedony overlain by drusy quartz. The chalcedony and quartz separated from the joint wall and the intervening space was almost completely filled with dense mosaic calcite consisting of <1 mm crystals with flat rhombohedral terminations on free surfaces. The calcite shows faint laminations parallel to the joint surface, especially under short-wave UV light, perhaps related to variable content of very-fine-grained tuffaceous impurities. The laminations may indicate progressive opening and infilling of the joint. There are also calcite overgrowths on the drusy quartz away from the joint surface. Rare pale yellow <1 mm aggregates of silica occur with calcite in the interstices of the drusy quartz crystals. The surfaces of the mosaic calcite deposits are locally covered with thin patches 1 to 3 mm across of water-clear botryoidal silica with blocky surfaces, probably opal-CT. An unidentified rose-lavender very fine-grained mineral on fractured surfaces of the mosaic calcite is rare but locally prominent.

E037-2 (Sta. 16+19)

The sample consists of mm- to cm-scale angular rock fragments in a matrix of sand-, silt-, and clay-size material that constitute a fracture filling. The smallest fragments are ≤0.1 mm. The rock fragments are densely welded, devitrified Topopah Spring Tuff, mostly orange-brown and gray, with vapor-phase alteration in the pumice clasts. Phenocryst content is ~15 to 25%, mostly feldspar. No UV-fluorescent phases were observed in any part of the sample.

The fine-grained matrix is composed mostly of chunks and elongate striated pieces of white to orange undeformed, translucent to chalky glass. Individual biotite crystals comprise ~5% of the sand-silt fraction.

APPENDIX C (continued)

SITE AND SAMPLE DESCRIPTIONS

The crystals are heterogeneous, including greenish, brown, orange-brown, “tarnished” examples. Many dark crystals have partly resorbed textures. Other mafic minerals include pyroxene, hornblende, and Fe-Ti oxides.

The abundance of clay-size material is ~10-20%. Centimeter-scale domains of the finest-grained material, without coarser components, show graded bedding from very fine sand to silt, capped with ≤1-mm thick layers of red-brown clay. The deposits are deformed and surrounded by coarser material.

The lithic fragments are derived from local bedrock, but the vitric material is derived from higher in the Topopah Spring section and must have moved tens of meters downward through an open fracture. The layered, fine-grained deposits formed by particle settling in water-filled spaces. The biotite content of the matrix is probably enriched relative to its abundance in overlying rock (Buesch et al., in press), suggesting concentration by aqueous suspended transport.

<u>E038-1 (Sta. 17+00)</u>

This systematic sample consists of red-brown, densely welded, devitrified Topopah Spring Tuff in irregular rough-surfaced fragments. The tuff contains ~10% phenocrysts of ≤1 mm feldspar, Fe-Ti oxides, biotite, and sphene. There are also ~10% 1-2 mm elongate vapor-phase patches in former pumice clasts, containing <1 mm cavities and <1 mm crystals of silica and feldspar.

The subsample includes one irregular incipient fracture with vapor-phase minerals and a <1mm rock fragment cemented by vapor-phase minerals. There is <1 % overall coverage of the rock surfaces by isolated <1 mm Mn mineral spots, many adjacent to lithic grains or mafic phenocrysts. The presence of the Mn coatings indicates that the rock fragment surfaces are natural and not caused by the air hammer during sample collection. No UV-fluorescent phases were observed.

<u>E040 (Sta. 18+96)</u>

The bedrock at the sampling site is lithophysal, densely welded, devitrified Topopah Spring Tuff. The lithophysal cavities are up to 0.5 m wide, and lithophysal fractures with vapor-phase mineral coatings are common. The rock is cut by many short-segment (<1 m), high-angle cooling cracks. Small amounts of calcite are present in the exposed rock, but not in the sampled material.

Rock fragments in the sampled material are mostly 5 to 10 cm across, angular, and equant to elongate. The smaller lithophysal cavities and partings, coated with vapor-phase minerals, are elongate parallel to the rock layering caused by flow and welding. The vapor-phase altered borders on the cavities and partings are up to about 1 cm thick. The <1 mm crystals lining the cavities and partings are feldspar, crystalline silica, and minor Fe-Ti oxides. Away from the central lithophysal cavities, the vapor-phase crystals are finer grained, <0.1 mm. Most rock fragment surfaces, especially those that are smoother and more planar (probable cooling cracks), have <<1 mm translucent to transparent coatings of probable cryptocrystalline silica. Locally, the silica has an equally thin overcoat of pale blue-gray clay. There is a dusting of loose to somewhat adhesive vapor-phase material on all rock surfaces. No calcite or UV-fluorescent silica was observed in the sampled material.

<u>E041-1 (Sta. 19+00)</u>

This systematic sample is mottled orange-brown and gray-pink, densely welded, devitrified Topopah Spring Tuff. The gray-pink areas are concentrations of mostly white, <1 mm vapor-phase crystals. The rock is broken into rough-surface, irregular fragments. A few tight, planar fractures, with original apertures <1 mm, are filled with vapor-phase white minerals and show no evidence of subsequent breakage or separation.

There is very slight development of <0.5 mm Mn patches adjacent to small lithic inclusions or phenocrysts. No short-wave UV-fluorescent phases were observed.

APPENDIX C (continued)

SITE AND SAMPLE DESCRIPTIONS

E042 (Sta. 19+31)

The sampled bedrock is lithophysal, densely welded, devitrified Topopah Spring Tuff. The abundant lithophysal cavities are less than 20 cm across. The rock is generally broken into mostly <10 cm fragments. Orientation and extent of the broken rock zone are unknown. There are no obvious throughgoing fractures, but a possible adjacent fracture zone parallel to the tunnel axis may have been mostly removed during mining. Calcite fillings in a cluster of lithophysal cavities about 1 m above and to the right of the collection site suggests a possible flow pathway.

There is preferential breakage and comminution of the vapor-phase altered margins of lithophysal cavities and vapor-phase altered pumice lapilli. This soft material is composed of <0.1 mm crystals of feldspar and crystalline silica. Networks of fine (<<1 mm apertures) fractures within the breccia clasts are filled with poikilitic calcite, and the surfaces of the clasts have <1 mm-thick coatings of poikilitic calcite with a variety of surface terminations. The pore spaces between the larger clasts, i.e., larger than a few millimeters, are not completely filled with calcite although the surface coatings are sufficient to form a tight cement. The calcite is not UV-fluorescent, and no fluorescent silica was observed.

E044 (Sta. 19+42)

The sample site is a crackle breccia zone in lithophysal, densely welded, devitrified Topopah Spring Tuff. The breccia zone is about 3 m wide and laterally bounded by discrete fractures. The breccia is fairly tight, with little or no realignment of the blocks. The breccia zone extends from the invert about halfway up the right rib, but the opposite rib shows more upward continuity.

Lithophysal cavities are up to about 3 cm across and lined with <1 mm crystals of feldspar, silica, and Fe-Ti oxides. The angular fragments are locally coated with <<1 mm crystals of vapor-phase minerals, suggesting that the fragmentation of the rock is at least partly syngenetic. A ubiquitous white powder on the rock surfaces contains vapor-phase minerals that may have been redistributed from lithophysae. UV-fluorescent calcite cement is widespread but not abundant. Coatings of <1 mm calcite crystals are located in some lithophysal cavities and adjacent surfaces of intersecting fractures. No UV-fluorescent silica was detected in the sample.

E045-1 (Sta. 21+00)

This is a systematic sample of densely welded, devitrified Topopah Spring Tuff. The mottled orange and pink-gray rock is in angular fragments with common <1 mm thick coatings of vapor-phase minerals (tridymite, other

E046 (Sta. 22+71)

The site is a near-vertical fracture zone about 6 m wide that extends about 2/3 of the distance from the invert to the crown. The bedrock is lithophysal, densely welded, devitrified Topopah Spring Tuff. Lithophysal cavities, mostly <30 cm, comprise about 40% of the rock, and there are numerous lithophysal fractures. Some of the fractures have calcite coatings, but no calcite was observed in the lithophysae.

The lithophysal cavities and fractures are commonly coated by <1 mm vapor-phase crystals of feldspar and Fe-Ti oxides. The highly irregular surfaces of the lithophysal fractures are also variably coated with at least three varieties of silica, as well as calcite. The least abundant variety is a combination of clear botryoidal and irregular lacy masses of UV-fluorescent opal. This material is overlain by drusy quartz crystals in a dense coating or open network, about 1 mm thick. Some quartz lies directly on the rock surface on or the vapor-phase feldspar. Some crystals are skeletal or hollow or form surface-conformal crusts, up to several cm across, of semi-aligned crystals with prism faces parallel to the rock surface. Examples exist in which the outer margins of quartz crusts are nonfluorescent and have a fairly sharp boundary with the fluorescent quartz, although no obvious morphological boundary is visible.

Sparry calcite forms <1 mm-thick, discontinuous coatings on the quartz, especially filling the interstices of the network and the centers of hollow crystals. A minor amount of calcite also occurs as film-like

APPENDIX C (continued)

SITE AND SAMPLE DESCRIPTIONS

crystal aggregates directly on the rock surface. Domains of fine-grained bedrock breccia, cemented by calcite and possibly by quartz, also exist.

E047-1 (Sta. 23+00)

This systematic sample is red-brown, densely welded, devitrified Topopah Spring Tuff. The rock contains ~1% elongate, <1 cm vapor-phase patches, pockets, and spherulites of white, <1 mm crystals of silica and feldspar, plus minor biotite. There are no Mn minerals or long- or short-wave UV fluorescent phases.

E050 (Sta. 24+40)

The sampled material is fault gouge and calcite from a near-vertical fault following an old cooling crack in lithophysal, densely welded, devitrified Topopah Spring Tuff. Some large lithophysal cavities are intersected by the fault trace, and many have calcite overlying the 1 cm-thick vapor-phase mineral coatings.

The gouge itself, as sampled, is uncemented and contains no detectable UV-fluorescent silica. A local deposit of calcite, separated for ^{36}Cl/Cl analysis, was the only calcite observed within the fault. Centimeter-scale clasts are subangular to subrounded and have scattered thin coatings of vapor-phase minerals, mostly feldspar and crystalline silica, typical of the smaller lithophysal cavities. Most clasts, including those <1 mm, are coated with light buff powdery material.

E052 (Sta. 26+79)

The bedrock is densely welded, devitrified Topopah Spring Tuff with >10% lithophysal cavities up to 0.5 m across. Some cavities are aligned parallel to adjacent or intersecting fractures, some of which are cooling cracks. The sampling site includes a near-vertical, probable cooling crack with multiple traces within a 1 m-wide zone, traceable about 3/4 of the distance from invert to crown. Fracture apertures are generally 1 mm. Fractures like this occur at about a 3- to 4-m spacing along the tunnel wall. There are no obvious coatings of calcite or manganese minerals on the fracture walls, but most of the larger lithophysae have 2- to 3-cm-thick crusts of 1 to 2 mm calcite crystals on the bottoms and sides of the cavities.

Smaller lithophysal cavities, a few centimeters across, have <1 mm-thick coatings of <1 mm crystals of feldspar, crystalline silica, and Fe-Ti oxides. Examination of one cooling crack surface revealed scattered 1 to 2-mm patches of very thin and very fine-grained blue-gray silica. None of the silica fluoresces in UV light. No calcite was observed in the small cavities or on the fracture surface.

E073-1 (Sta. 5+04)

This sample consists of angular to subangular ≤4-cm fragments of densely welded, devitrified Tiva Canyon Tuff. The fragments are mottled red-brown and gray. Patches and less common dendrites of red-brown Mn minerals, ≤1 mm across, rest directly on the rock fragment surfaces. The overall abundance of the Mn minerals is ~1%, but the material is locally more abundant. There are also local <<1-mm-thick coatings of white clay. The fragments have loose coatings, up to 1 mm thick, of white powdery material. No short-wave UV-fluorescent phases were observed.

E141-2 (Sta. 29+0)

The sample is densely welded, devitrified Topopah Spring Tuff. Cavity surfaces and fractures have <1-mm thick coatings of <1-mm white crystals of feldspar and minor black Fe-Ti oxides. No UV-fluorescent phases were observed.

E142-2 (Sta. 29+21)

The examination subsample is red-brown, densely welded, devitrified Topopah Spring Tuff with 1 to 2% phenocrysts. Spherulitic devitrification, with <1 mm spherules, is associated with relict pumice clasts.

APPENDIX C (continued)

SITE AND SAMPLE DESCRIPTIONS

One fracture surface in the sample is subplanar but irregular due to vapor-phase alteration of the rock. The surface has a ≤1-mm deposit of <1 mm silica crystals, including tridymite, and 2-3% euhedral, skeletal crystals of hematite. A bleached margin is locally developed adjacent to the fracture surface. Another fracture, perpendicular to the first, is irregular and subplanar with a vague ~1 mm bleached margin. Patchy <1-mm-thick white coatings of ≤0.2 mm vapor-phase crystals are mostly silica. No Mn coatings or short-wave UV-fluorescent phases were observed. Particulates are of uniform color and are considered to be products of mining.

E145-2 (Sta. 29+80)

The sample was collected from two lithophysal/devitrification cavities about 2 m apart along a low-angle cooling joint of about 10-m extent. The cooling joint has been modified by brecciation.

The examination subsample consists of ≤1-cm-thick elongate fragments of densely welded, devitrified and vapor-phase devitrified Topopah Spring Tuff. There are also a few subequant cm-scale fragments; most are almost completely covered by ≤1-mm-thick white coatings of <1 mm vapor-phase crystals. The rock fragments are coated by calcite and less abundant opal in coatings up to ~3 cm thick. Opal is more restricted in occurrence than calcite.

The calcite fluoresces weakly white in short-wave UV light. Most of the calcite is in dense (<5% porosity) intergrowths of irregular flat rhombohedral crystals, ≤1 cm across, in groups of subparallel crystals. The crystals, many with short dimensions perpendicular to rock surfaces, are gray with glassy to slightly pearly luster.

About 50% of the calcite has <1-mm-thick overgrowths of clear opal with bumpy, rounded surfaces. The opal fluoresces strongly yellow-green in short-wave UV light. There are also opal layers and patches within the calcite coatings.

Calcite coatings on opposite sites of flat rock fragments are noticeably different. The original orientations of the samples have not been preserved, but it is probable that underside coatings have thinner, more porous calcite layers. The calcite is glassier and in smaller, better formed crystals, some <1 mm, with both flat rhombohedra and prismatic forms. The smallest crystals are in localized lacy aggregates. There is no associated opal.

The rock fragments contain incipient fractures with <1 mm apertures, subparallel to the flat rock surfaces. Many fractures are filled with mostly monocrystalline calcite. There is also some poikilitic cementation of vapor-phase altered rock by calcite. No Mn minerals were observed.

E146 (Sta. 30+18)

The analyzed mineral separate is from a lithophysal-devitrification cavity about 1 m across in densely welded, devitrified Topopah Spring Tuff with <5% lithophysae in an area of few throughgoing fractures. The cavity is intersected by at least one cooling crack with smooth surfaces and bleached margins.

Resting on the bottom of the cavity are loose crusts of platy, pearly calcite aggregates up to ~2 cm thick. There are many local textural varieties of calcite. Common forms, all less than 1 mm long, include steep rhombohedra grouped on the surfaces of larger crystals, tapering hairlike crystals, and beadlike strings of crystals. Many of these forms have textural features suggestive of both deposition and dissolution. In some places, extremely thin, ribbonlike calcite aggregates have grown as much as several centimeters upward from the crystalline crusts.

Clear opal-A occurs locally with calcite as intergrowths and, more abundantly, as thin overgrowths. Both the calcite and the opal fluoresce in short-wave UV light.

E148-2 (Sta. 31+61)

The sample consists of densely welded, devitrified Topopah Spring rock and vapor-phase fragments cemented by calcite, from an incipient lithophysal cavity intersected by a cooling joint subparallel to the tunnel wall and another cooling joint dipping ~30° to the north. Where the calcite cements tuff fragments,

APPENDIX C (continued)

SITE AND SAMPLE DESCRIPTIONS

it occurs locally in cm-scale poikilitic crystals. The presence of lacy crystal surfaces and <1 mm tapered narrow crystals may be evidence of dissolution.

The calcite crust from the cavity is ~1 cm thick. Crystals on the upper part of the crust are 1-mm to 1-cm short prismatic forms of variable orientation. There are local cm-scale areas of lesser deposition or, more rarely, of nondeposition. The calcite is slightly fluorescent under short-wave UV light. No fluorescent silica was observed.

<u>E149-2 (Sta. 31+63)</u>

The sampled material is crushed tuff breccia along a cooling joint in densely welded, devitrified Topopah Spring Tuff. The joint is traceable from invert to crown, and at least one joint surface is coated with calcite.

The mm- to cm-scale breccia fragments are equant to flat and elongate, and have some smooth, planar faces and irregular rounded faces, both with bleached margins. One cooling joint surface of a fragment has a <1-mm-thick coating of <1 mm feldspar and silica crystals. One smooth fragment surface, without a bleached margin, has a ~1-mm-thick coating of laminated white to pale yellow, translucent clay overlying a <1-mm-thick layer of <<1-mm tuff fragments. Most fragments have very thin dustings of powdery material and scattered <1-mm spots of manganese minerals. No UV-fluorescent minerals were observed in the examination aliquot.

<u>E150-2 (Sta. 33+00)</u>

This systematic sample of densely welded, devitrified Topopah Spring Tuff is gray-red with ≤5 mm pumices and several cm-long, highly flattened red-orange pumice fiammi. Spherulitic devitrification and rare vapor-phase cavities are localized in relict pumice clasts. There are a few planar, slightly rough fractures parallel to the alignment of flattened pumice clasts. Rare deposits of <1 mm patches of Mn minerals are present on the fracture surfaces. No short-wave UV-fluorescent phases were observed.

<u>E151-2 (Sta. 33+16)</u>

The sampling site is a 0.5-m lithophysal cavity with fillings of calcite and opal. The cavity is intersected by at least one vertical cooling joint. The cavity is lined with ~1-mm-thick coatings of <1-mm feldspar, silica, and Fe-Ti oxide crystals.

Calcite crystals immediately overlying the vapor-phase linings are equant and ~1 mm across. Where the calcite is separated from the vapor-phase linings, there are a few <1-mm crystals of prismatic or dog-tooth calcite crystals that grew downward from the main mass of calcite. Overlying crystals, in fairly dense aggregates, are platy and up to 1 cm across. Most platy crystals are oriented with thin dimensions horizontal. Fragments of vapor-phase linings are imbedded in the upper parts of the calcite aggregates. The calcite fluoresces purple in short-wave UV light.

Three textural varieties of silica, all of which fluoresce in short-wave UV light, are present. Coatings, <<1 mm thick, of clear opal with round protuberances cover ~50% of the calcite surfaces in cm-scale patches. Similar material may be included in the interiors of some calcite crystals as well. Patches of individual <1-mm hollow yellowish silica spheroids form deposits on calcite. The overall abundance of this silica variety is <1%. The spheroids are slightly granular on the outer surfaces and have a powdery appearance on the hollow inner surfaces. Some spheroids are partly overgrown by calcite. In addition, there are rare 1-2 mm aggregates of translucent, gray-white botryoidal silica. Individual botryoids are <1 mm across. The surfaces of the botryoids are covered with clear opal. The textural relations of this silica variety with calcite are uncertain.

<u>E153-2 (Sta. 34+32)</u>

This breccia sample was collected from a cooling joint with variable brecciation and about 1 to 2 cm of offset. The joint, within densely welded, devitrified Topopah Spring Tuff, is oriented 031-86 W. Minor calcite is present within the joint, but the examination subsample does not contain calcite.

APPENDIX C (continued)

SITE AND SAMPLE DESCRIPTIONS

The examination subsample consists of one 9-mm thick piece of breccia fracture filling. The thickness of the filling is very uniform, and the outer surfaces are planar and fairly smooth. The filling is moderately cohesive, with less than ~5% porosity. Constituents include ~80% angular and subangular, mostly equant fragments of mottled orange and pink-gray, densely welded, devitrified tuff. The fragments are 1 to 10 mm across, and many contain incipient cracks. About 10% of the breccia consists of white aggregates, ≤1 mm across, of <1 mm vapor-phase crystals. Gray detritus <<1 mm, rich in vapor-phase crystals, slightly clayey, and molded around rock fragments comprises about 10%.

The outermost <0.5-mm-thick portions of the deposit consist of a variably distinct gray layer of loosely cohesive <0.1 mm vapor-phase crystals. There are minor black or brown ≤1 mm patches of Mn minerals on rock fragment surfaces and on the outer surfaces of the breccia filling. In a few places, there are indications of a coating underlying the outer vapor-phase granular layer. No long- or short-wave UV-fluorescent phases were observed.

E154-2 (Sta. 34+71)

Breccia and adjacent wall rock of densely welded, devitrified Topopah Spring Tuff were collected from a high-angle ~NNE cooling joint with cm-scale offset. There is discontinuous brecciation along the joint trace. Minor calcite deposits are located on the joint surfaces. Subsamples of the slightly clayey breccia and the adjacent rock, including fracture surfaces, were collected.

A 1- to 5-cm-thick breccia filling from between cooling crack surfaces is moderately cohesive but friable. The angular to subangular fragments vary from ~1 cm to <0.1 mm. Many mm-scale fragments are easily crumbled. The rock fragments are mostly orange with lesser gray-brown mottling. Fragments larger than ~1 mm have <<1-mm-thick, discontinuous coatings of white clay. The outermost few mm of the breccia filling contain additional tan clayey-silty material, and the outer surfaces of the breccia filling are coated with white-tan clay, slightly less than 1 mm thick and without silt. In some places, this coating has cracked cleanly away from the adjacent breccia.

Common, but not abundant, <1 mm dendritic patches of brown submetallic Mn minerals are present on rock fragment surfaces. Some patches surround primary or syngenetic metallic oxide grains. In a few places, the Mn coatings adhere to the clayey matrix separated from a rock fragment. No short-wave UV-fluorescent phases were observed.

E155-2 (Sta. 35+00)

This is a systematic sample of densely welded, devitrified, nonlithophysal Topopah Spring Tuff. The site is within a zone of broken rock with throughgoing, subvertical cooling joints. The cooling joints are common, with several orientations, and have smooth, planar surfaces. Some fracture traces are discontinuous on a 4- to -5cm scale and abut fractures of slightly different orientation.

The tuff is gray-brown, with local spherulitic devitrification and very slight development of ~1 cm lithophysal cavities. Cooling joints have slight development of bleached margins. All planar fracture in the examination subsample have vapor-phase coatings up to 1 mm thick. The constituents are feldspar, silica, and very minor Fe-Ti oxides. The coatings are powdery to hard. Other more irregular fractures are mostly without vapor-phase deposits.

There is much less than 1% coverage by yellow-brown and red-brown Mn minerals on cooling joints and other fractures. The minerals are in patches up to 2 mm and in discontinuous elongate, dendritic patches following the texture of the vapor-phase substrate. Several of the rougher-surfaced fractures have minor scattered <1 mm deposits,<<1 mm thick, of blue-white translucent clay. Discontinuous deposits <<1 mm thick of tan silty material, some together with clay, are common on rough fracture surfaces. No short-wave UV-fluorescent phases were observed.

E157-2 (Sta. 35+03)

This sample is from a zone of broken rock and cooling joints in nonlithophysal densely welded, devitrified Topopah Spring Tuff. A cooling joint forms the lower boundary of the collection area. The

APPENDIX C (continued)

SITE AND SAMPLE DESCRIPTIONS

open-textured breccia consists mostly of angular thin to equant fragments ≤4 cm across. There are some domains of finer grained, mostly ≤2 mm fragments, locally clayey. The breccia also includes <2% fragments of white very fine-grained vapor-phase material, mostly feldspar.

The breccia is cemented by calcite that fluoresces blue-white in short-wave UV light. The calcite is mostly in networks of thin flat, pearly crystals. Crystal sized vary from <1 mm to ~5 mm. The larger crystals appear compound, possibly twinned, and occur in segregated rosettes. They fluoresce more strongly than the smaller crystals. The smaller crystals occur in finer grained breccia and along what may be surfaces that faced fracture walls bounding the breccia. In a few areas, the smaller crystals have tapering, knobby, rounded surfaces suggestive of dissolution.

There are also rare dendritic manganese deposits on tuff clast surfaces. No UV-fluorescent silica deposits were detected.

<u>E158 (Sta. 35+08)</u>

The sample site is a breccia zone about 6 cm wide between two parallel cooling joints. The high-angle joints are oriented ~SSW and are intersected at the sample site by a low-angle ~E-W cooling joint. Both joint surfaces adjacent to the breccia are polished and have minor coatings of waxy-texture calcite. The very loose crushed-tuff breccia and the adjacent fracture surfaces and bedrock were collected as subsamples.

The densely welded, devitrified Topopah Spring Tuff is mottled gray brown and lesser orange. The rock is broken into cm-scale or smaller fragments, with broken zones bounded in part by subparallel smooth planar fracture surfaces with no sign of vapor-phase minerals or bleached margins. Other fracture surfaces are rougher and more irregular. Disintegrated white phenocrysts, ~1 mm across, are prominent and comprise ~1%. Other phenocrysts are less altered.

Brown patches of Mn minerals, ≤2 mm across, are present on the rock fragment surfaces. The overall abundance is ~1%; local coverage is as much as 10%. Coatings of white (transparent where very thin), tan, and pink-gray-brown clay, <1 mm thick, are common and locally abundant, with overall coverage of about 10-15%. The coatings are most noticeable on smooth fracture surfaces, but are also present on some rougher surfaces. No short-wave UV-fluorescent minerals were observed.

<u>E160-2 (Sta. 35+45)</u>

This sample was collected from a zone of perpendicular sets of near-vertical cooling joints with bleached margins, backed by a very well developed ~N-S fracture subparallel to the tunnel wall. Fractures in the set perpendicular to the N-S fracture contain calcite, but the examination subsample contains no calcite.

The examination subsample is orange-brown, densely welded, devitrified Topopah Spring Tuff, including one smooth planar fracture with a ~1 mm bleached margin. On the fracture surface is a ≤1-mm-thick compact deposit of <0.5 mm white vapor-phase crystals. Manganese minerals lie on top of the vapor-phase deposit.

Other rock surfaces are rough and irregular, with minor surface deposits including a variety of white to blue-white, waxy to powdery deposits of clay ± mordenite, with ~1% overall coverage, but locally as much as 50% coverage. The deposits are <1 mm thick and may have slightly ropy textures. Similar but separate deposits of pale orange-pink color are also present. White to pale orange, slightly cohesive, <0.5 mm thick powdery deposits have an overall abundance of <1% on rock fragment surfaces but achieve 50% coverage. This material may be a mixture of translocated vapor-phase minerals and minor clay. There are also isolated <1 mm dendrites of Mn minerals, with overall coverage <1%. Some of the Mn dendrites overlie fine-grained particulate layers, confirming that the particulates are not construction dust. No short-wave UV-fluorescent phases were observed.

APPENDIX C (continued)

SITE AND SAMPLE DESCRIPTIONS

E161-2 (Sta. 35+58)

The sample site is a low-angle cooling joint intersected by two sets of high-angle fractures. The sampled fracture and the intersecting fractures form a boundary between a ~15-m interval of highly broken rock to the north and unbrecciated rock extending tens of meters to the south. Brecciated rock immediately below the low-angle joint is cemented by calcite.

The cm-scale fragments of densely welded, devitrified Topopah Spring Tuff are mostly flat and elongate. About half the fragment surfaces are smooth and planar, half to two-thirds of the surfaces have vapor phase coatings, and a few have bleached margins. All of these characteristics are indicative of syngenetic fracturing. The vapor phase coatings, up to ~1 mm thick, are composed of silica, feldspar, and Fe-Ti oxides. Some coatings are made up of crystals ≤1 mm, while other coatings are powdery looking and made up of ~0.1 mm crystals. The finer grained coatings are more loosely adhering to the rock surfaces but are somewhat cohesive.

Calcite, weakly fluorescent in short-wave UV light, occurs as coatings, ~0.5 mm to 1 cm thick, on rock fragment surfaces and cements smaller clasts. Most calcite crystals are flat, prismatic, and slightly pearly, in thin coatings consisting of several mm-scale monocrystalline domains, usually on bare rock surfaces. Dog-tooth calcite crystals <1 mm across occur in lithophysal cracks. Calcite overlies both vapor-phase coatings and bare rock.

Blue-gray translucent clay forms localized coatings, <1 mm thick on rock surfaces and calcite, with <2% to about 5% coverage. White to pale yellow-white, chalky clayey material locally encrusts calcite crystals. Some rock surfaces and calcite aggregates are partially coated with <1-mm-thick, loosely adhering sand-size material and white to reddish-brown clay. Widespread, but not ubiquitous or abundant, ≤1-mm spots and diffuse stains of black to yellow-brown manganese minerals are present on rock surfaces, on powdery vapor-phase deposits, and rarely on calcite. No fluorescent silica was observed.

E160 (Sta. 35+45)

The bedrock at this site is densely welded, devitrified Topopah Spring Tuff. The sample site contains two nearly perpendicular sets of vertical fractures with dm-scale spacing. The vertical fractures oriented ~E-W are cooling joints with bleached margins and contain calcite, whereas no calcite was observed in the fractures oriented ~N-S.

E175-2 (Sta. 35+58)

This sample was collected along a trace of the Sundance fault. The fault at this location consists of two intersecting traces. Both traces include cm-scale zones of fine- to medium-grained, slightly clayey breccia marked by horizontal slickensides. The densely welded, devitrified Topopah Spring bedrock has an overall fabric of short-trace (cm- to dm-scale), subhorizontal fractures with moderately rare calcite deposits.

The breccia clasts are composed of red-brown, densely welded, devitrified Topopah Spring Tuff. The clasts, varying from ~7 cm to <0.1 mm, are angular and equant to elongate. Round patches, ≤0.5 cm across, of vapor-phase minerals are present on clast surfaces. The finest material, <0.1 mm, is commonly more whitish than the larger fragments, reflecting a high content of vapor-phase-derived material. The fine material also contains euhedral vapor-phase mafic and oxide crystals.

There is very little clay in the finest material, as shown by an absence of plasticity or cohesion when wetted. On a few newly separated fracture surfaces of breccia clasts, there are orange-brown clay skins <<1 mm thick or lobes of whitish particulates projecting inward from the fragment boundaries. Coatings of blue-white clay±mordenite, <0.1 mm thick, are also present though rare on the newly broken-apart fracture surfaces.

The breccia has less than ~5% porosity. There are 6- to 7-cm domains of much more cohesive breccia, disaggregated with a hammer, showing evidence of tuff fragment cementation by vapor-phase minerals. No long- or short-wave UV-fluorescent phases were observed.